Polarimetric tests with new Nasmyth optics

A. Sievers, G. Paubert, C. Thum, and I. Agudo

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Abstract

Following the upgrade of the Nasmyth optics in April 2015 we conducted a series of tests aimed at verifying the correct operation of XPOL. The new location of the XPOL calibration unit has no effect on the polarimetric calibration nor do the side-lobes increase as might be expected from the optical path now being closer to the cabin wall. We found the sign of Stokes V is systematically different between corresponding upper and lower sidebands at 3, 2, and 1.3mm. An explanation of this effect is given, and we show how to handle this effect.

1 Motivation

An upgrade of the Nasmyth optics in the receiver cabin of the 30m telescope was initiated in April 2015, aimed to provide a larger field of view mainly for the NIKA–2 camera. Nasmyth mirrors #3 and #4 were relocated and mirrors redirecting the EMIR beams were moved closer to the wall of the cabin. (see [2015]) This implied the relocation of the XPOL calibration unit including its movable grid. These changes potentially affect basic functionalities of XPOL and thus motivated the commissioning tests described here. A few more tests were made to verify the correct operation of XPOL in a recently developed mode where two frequency ranges in EMIRs lower and upper sideband are observed simultaneously.

2 Basic functionality

The calibration of the phase of the cross correlation is made in an XPOL specific forth subscan where the EMIR beam is redirected toward an external LN_2 load and a wire grid is inserted into the beam path. The correct positioning of the grid in its 3 possible locations (in front of any of the 2 EMIR windows or retracted) under remote control was verified. Some initial vignetting caused the amplitude of the cross correlation to be low. It is now back to its usual magnitude of ~100 K. No error of the total power calibration was noted when the external calibration signal was used.

3 ONOFF observations

Relocation of mirrors in the EMIR path may change the symmetry of the horizontally and vertically polarized beams and thus affect instrumental polarization. We investigated this issue by making a series of standard XPOL continuum on-off observations of Mars over the elevation range from 30 to 75 degrees. (Fig.1) shows the result after processing with the XPOL package in CLASS. On the left-hand are shown the stokes

band	Stokes	pattern type	maxima, %		PA	remark
3mm	Q	irregular	+0.8	-1.2	—	very asymetric
	U	3–lobed	+0.8	-0.3	—	pos. lobe on axis
	V	bipolar	+1.2	-2.1	~ −45	pattern offset
2mm	Q	bipolar	+1.2	-1.0	+60	pattern offset
	U	3–lobed	+0.8	-0.9	—	
	V	bipolar	+2.1	-0.8	~ 30	pattern offset
1mm	Q	bipolar	+2.0	-1.8	~ 30	pattern offset
	U	3–lobed	+1.3	-2.2	~ 0	elevation 37
	V	bipolar	+1.4	-1.0	~ −100	

Table 1: Main characteristics of sidelobe patterns. PA gives the position angle of the pattern (direction to positive peak from (x,y) origin, whenever applicable).

parameter values for the LO subband of the E230 and on the right-side the UO subband. From the bottom to the top are shown stokes I in antenna temperature, above that stokes Q in percentage of I, likewise for U and V. The sign change between the LO and UO band for stokes V, discussed further below, is clearly seen in this figure too. Stokes Q has a fairly small dependency on elevation, but stokes U shows a fairly large instrumental value (-2 to -4 %), that also varies with elevation. Fortunately this dependence with elevation is almost linear over the shown elevation range.

4 Maps

Due to the relocation of Nasmyth mirror #4 as close as possible to the wall of the receiver cabin, the EMIR beams may be subject to pick up more load from ambient temperature surfaces. As reflections from these surfaces are likely to be polarized, they may increase the power in the polarized side-lobes. On 27–Jul–2015 we made several maps of Mars (size 3.6”) to investigate this issue.

A second motivation arises from the recently introduced XPOL observing mode where two VESPA bands are simultaneously observed, one being connected to the lower side band (LSB) of EMIR and the other one to the USB. This observing mode is well suited to detect subtle differences in polarization properties across the frequency range separating the two sidebands. Our tests on the unpolarized Mars aims to unveil any calibration errors in this complicated mode (and others), for example in the notoriously difficult determination of the signs of the Stokes parameters.

On 27-Jul-2015 observing conditions were good when the 1mm and 2mm data were taken. Good 3mm data were taken on 01-Sep-2015. The lower–outer (LO) and upper–outer (UO) sidebands of EMIR, separated by 20 GHz, were connected in parallel to the VESPA backend. For each map (duration 38 min) coverages in azimuth and elevation were averaged. The polarized sidelobes are well detected in all Stokes parameters Q, U, and V at all 3 bands (3mm, 2mm, and 1mm, see Figs. 2,3,4, respectively). These 3 maps, all observed in the LO subband, form a homogeneous data set, as they were taken under stable EMIR and Nasmyth optics conditions, and they constitute a reference set in view of further EMIR and optics modifications.

Tab. 1 summarizes the main characteristics of the maps. We obtained 2 pairs of maps at 1mm and 3mm where the connection sideband/Vespa part (LO→V01, UO→V02) was reversed. No significant difference was seen at any wavelength, ruling out any possible calibration errors or mix up of data streams at this level.

We note that the orientation of the sidelobe patterns with respect to the (x,y)

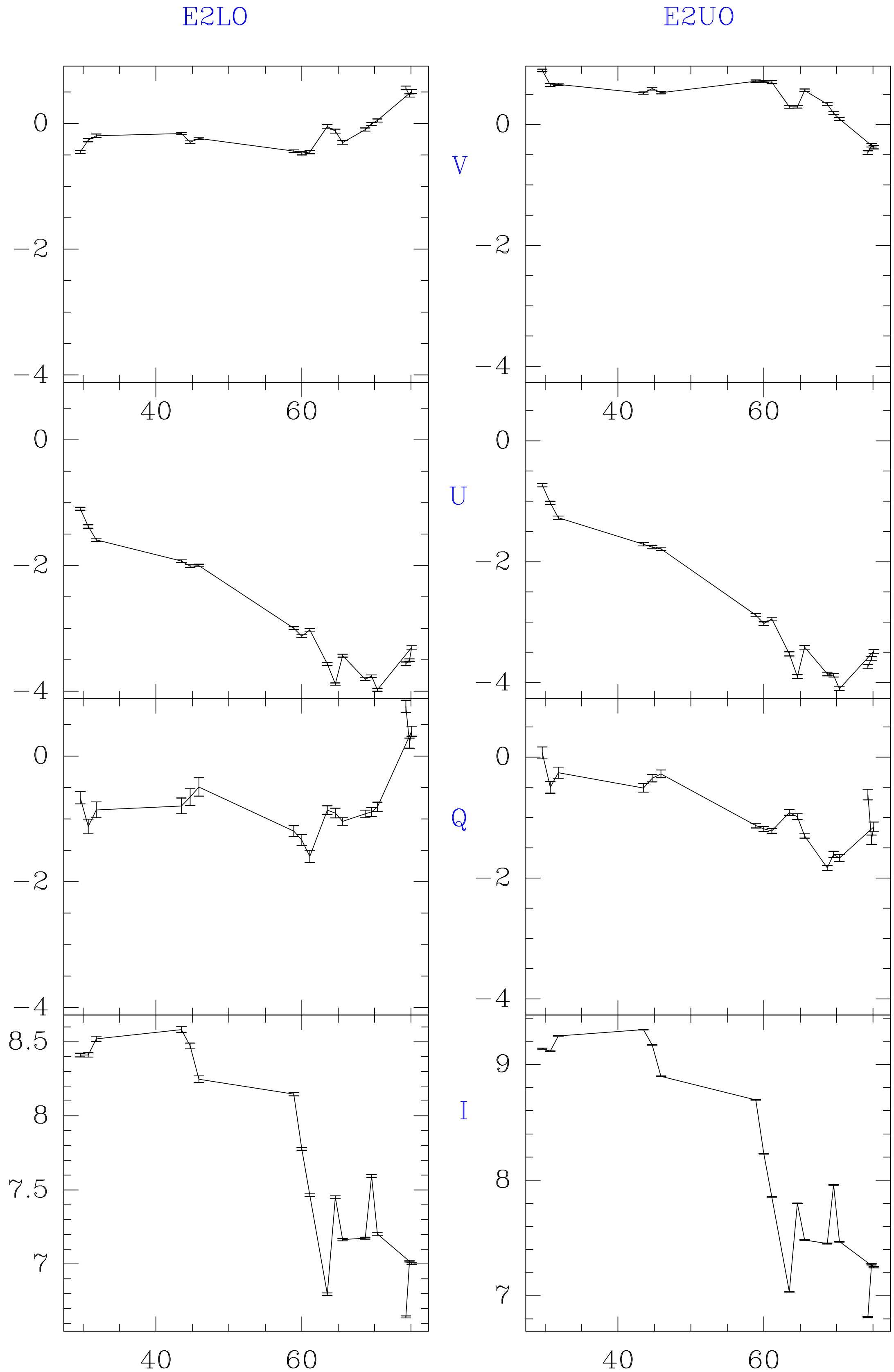

Figure 1: XPOL observations of Mars (Stokes I, Q, U, and V) A 300 MHz band of VESPA was connected to the lower–outer subband at 224.02 GHz of the E230 EMIR band, and a second 500 MHz wide band was connect to the upper–outer sideband at 242.88 GHz. Stokes I is shown in Antenna temperature, Stokes Q, U and V are shown as percentage of I.

Nasmyth coordinates is fixed only in the case where the instrumental polarization is exclusively generated in the Nasmyth cabin. This seems to be the case for Stokes V. Stokes U however rotates with respect to the (x,y) system in a sense compatible with the change of elevation. This behavior was observed before (see [2011]) where it was attributed to rotation of the differential illumination pattern on the subreflector. The situation for Stokes Q is unclear.

Contrary to the Stokes I, Q, and U maps which are identical within observational noise between the LO and UO sidebands (as well as under exchange of VESPA parts), Stokes V shows a systematic reversal of the sign between LO and UO in all 3 bands (Fig. 5). This sign reversal was already suspected earlier from much lower sign/noise observations of SgrA$*$, an observing project where the observing mode with LSB and USB in parallel was first used systematically.

This inconsistency between the LSB and USB signs of Stokes V is easily traced back to a wrong sign of the instrumental phase ϕ in one of the sidebands. Such an error clearly does not affect Stokes I and Q, both obtained as power measurements. Since Stokes U is proportional to $\cos\phi$, it is unchanged under sign reversal of ϕ. Only Stokes V changes sign due to $V \propto \sin\phi$.

The cause of the sign reversal of the instrumental phase between LSB and USB is well understood from the basic construction of mixers products, but the implementation is subtle. We will most likely implement this sign change in the calibration program and not implement an sign change in the data stream from the backend.

We have assigned a positive sign to subband LI, most often used in circular polarization observations with XPOL, assuming that the astronomical phase of of an incoming wave is correctly recovered in the calibration program MIRA for this subband. This means that the sign of Stokes V is correct (positive spectral features are right–hand circularly polarized) for subbands LI and UO, while the signs in the other sidebands has to be reversed. This sign reversal must currently be made in CLASS, but should be incorporated in the MIRA successor MRTCAL.

5 Conclusions

Following the upgrade of the Nasmyth optics in April 2015 (larger mirrors #3 and #4, location of EMIR mirrors and XPOL calibration unit closer to the wall, we have verified the correct operation of XPOL in all bands. ONOFF observations of Mars at 1.3mm over a large elevation range show a variation of the on–axis gain which appears to be nearly twice as large as expected from the 1mm gain/elevation curve. (see [2012]) We tentatively attribute this unexpected behavior to worsening atmospheric stability when the high elevation data were taken. Stokes Q and V gains vary little, $< 2\%$ with elevation. Stokes U displays a monotonous decrease by 3% from low to high elevations. This unexpected feature needs confirmation.

Using data from 5 different observing sessions, we obtained a homogeneous set of XPOL maps at 3, 2 and 1.3mm which can serve as a reference with respect to future modifications of EMIR or Nasmyth optics. The polarized sidelobes display the expected pattern: irregular in Q, 3–lobed or more complex in U, and bipolar in V. The maxima of the sidelobes never exceed 2.2%. The EMIR beam path which is now closer to the cabin wall than before, does therefore have no adverse effect.

The set of XPOL maps at three EMIR bands clearly demonstrates that the sign of Stokes V in the upper side bands is systematically inverted with respect to the corresponding lower sideband. This behavior, although not appreciated before, is a straightforward consequence of frequency conversion. We give advice on how to handle the sign of Stokes V for the different EMIR bands.

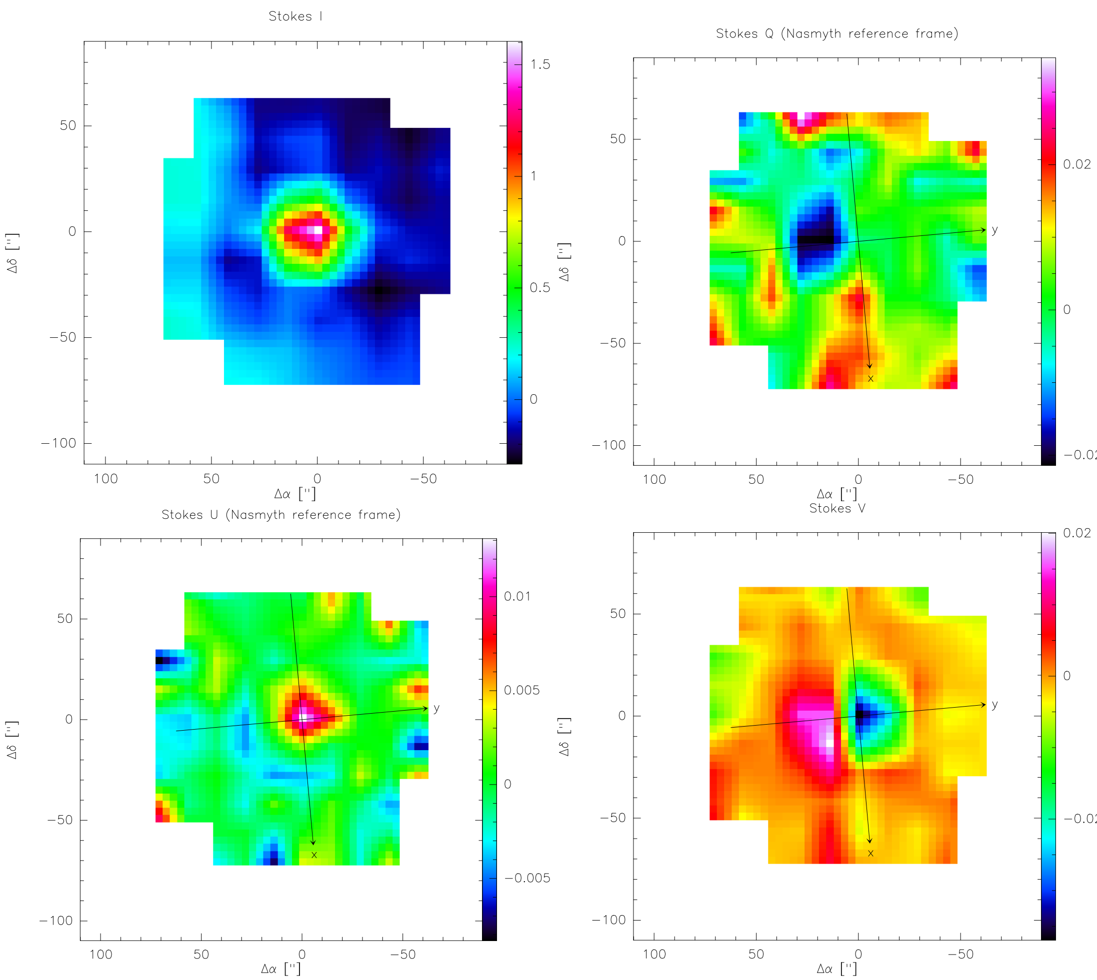

Figure 2: XPOL observations of Mars (Stokes I, Q, U, and V) at 3mm (LSB) on 01-Sep-2015. The (x,y) axes indicate the horizontal and vertical in the Nasmyth cabin. Elevation 37.0°. A 300 MHz band of VESPA was connected to the lower–outer subband of EMIR, and a second 500 MHz wide band was connect to the upper–outer sideband.

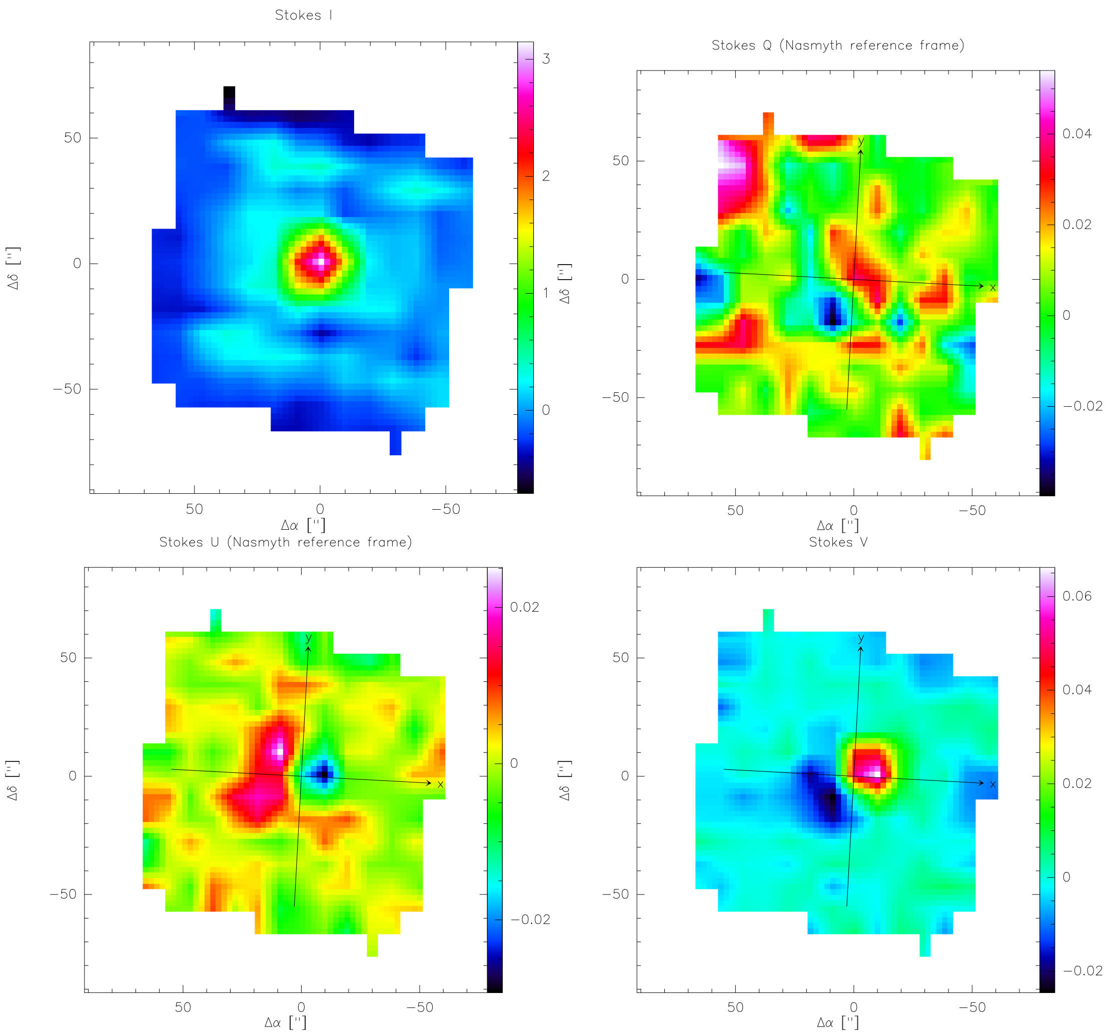

Figure 3: Same as Fig. 2 but at 2mm (LO). Observations made on 27-Jul-2015. Elevation 65.6° .

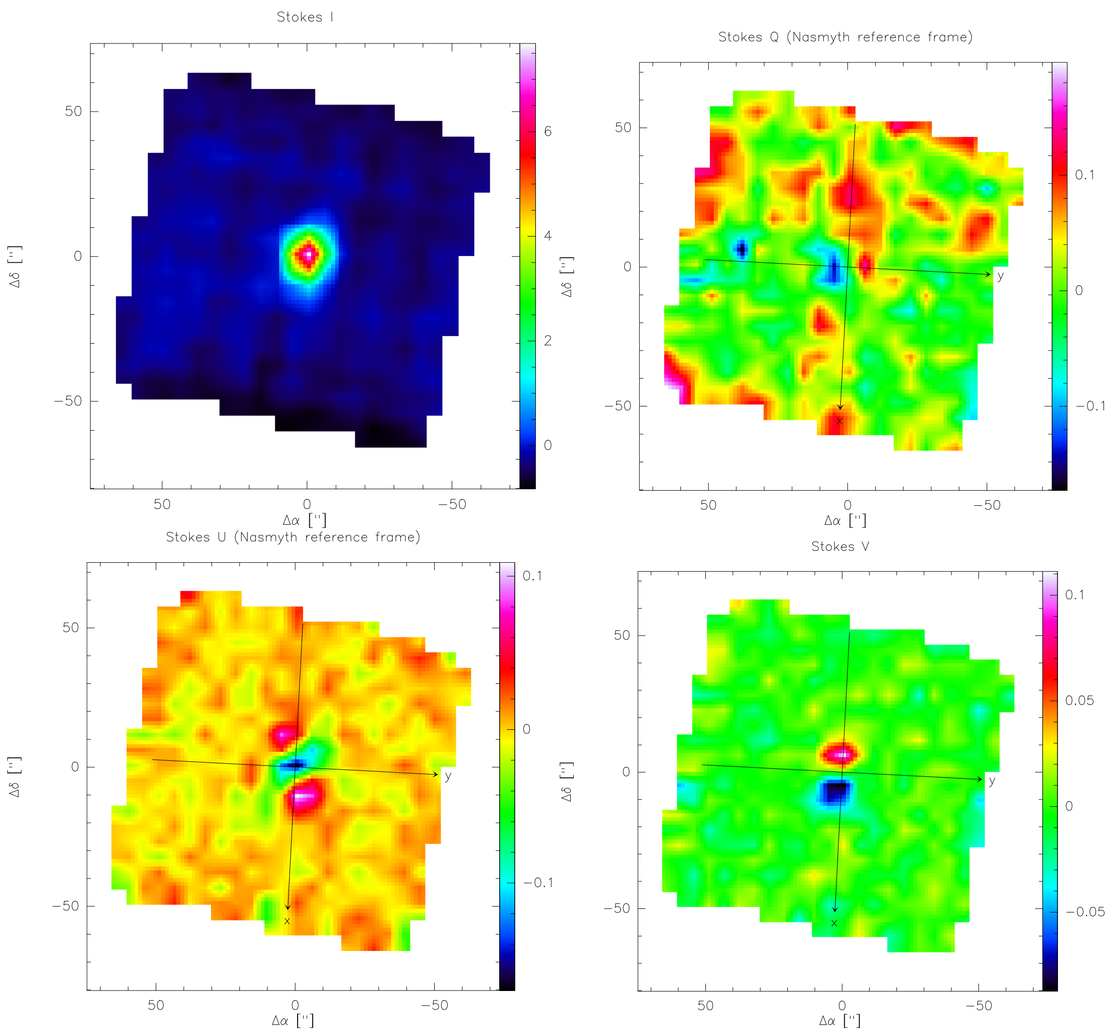

Figure 4: Same as Fig. 2 but for 1.3mm (LO). Observations made on 27-Jul-2015. Elevation 24.1°.

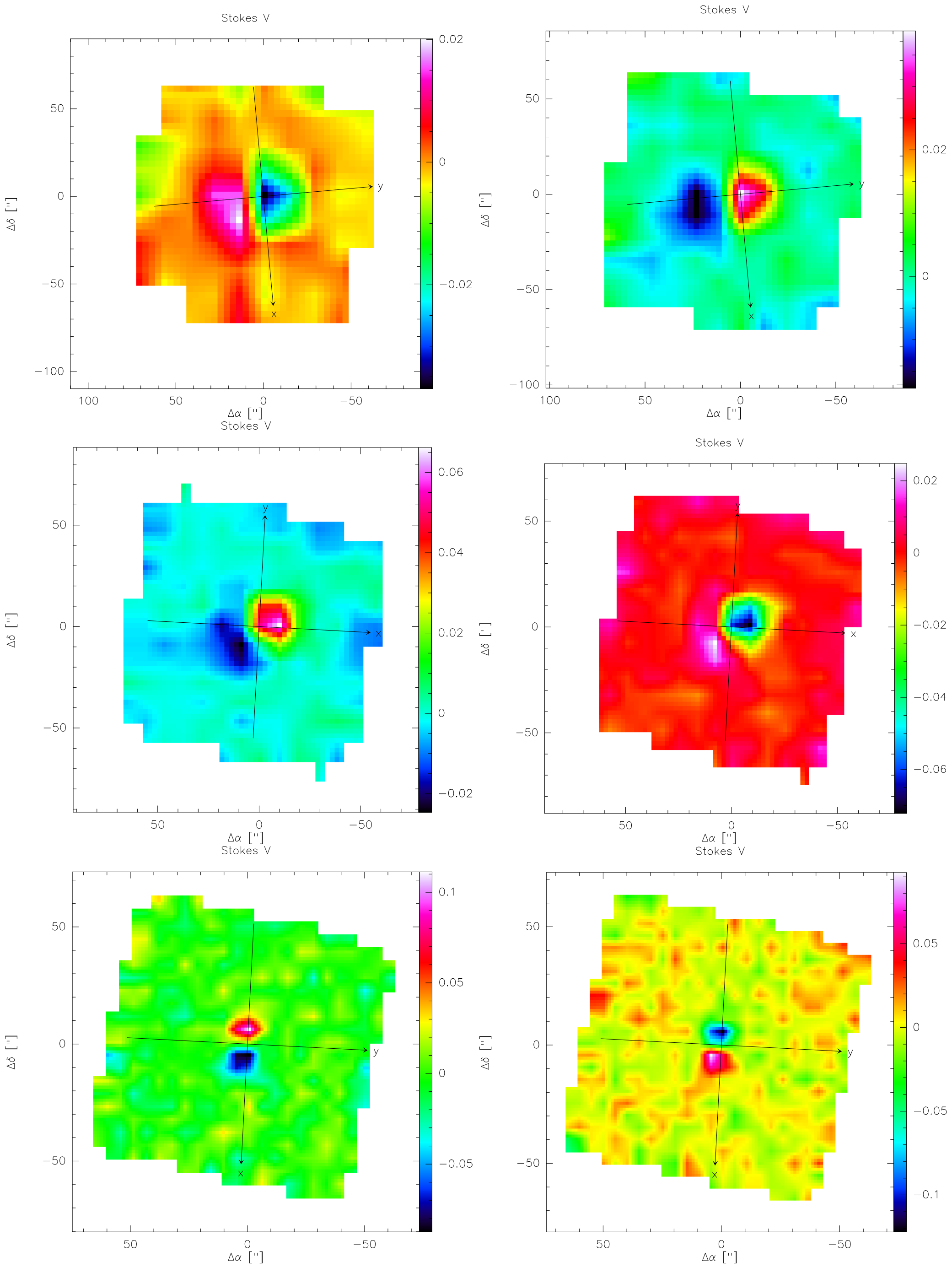

Figure 5: Stokes V beam maps of Mars at the 3 (top), 2 (middle), and 1.3 mm (bottom) EMIR bands. The size of the planet was 3.6" on 27-Jul-2015 (1 and 2mm) and 3.7" on 01-Sep-2015 (3mm). For each band, the simultaneously observed LSB (left) and USB (right) maps are shown. The (x,y) axes indicate the horizontal and vertical in the Nasmyth cabin.

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6 References

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